Performance characterization of UV science cameras developed for the Chromospheric Lyman-Alpha Spectro-Polarimeter (CLASP)

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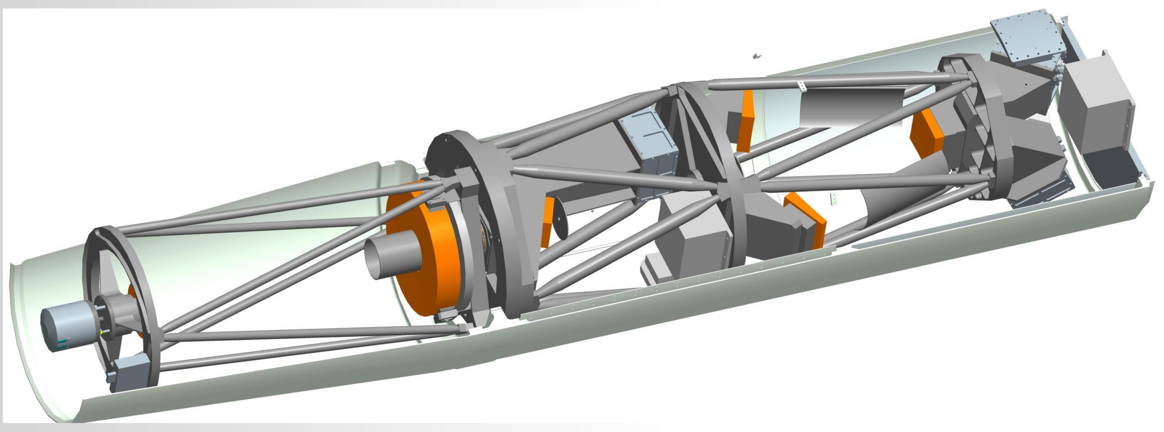
Abstract

The NASA Marshall Space Flight Center (MSFC) has developed a science camera suitable for sub-orbital missions for observations in the UV, EUV and soft X-ray. Six cameras will be built and tested for flight with the Chromospheric Lyman-Alpha Spectro-Polarimeter (CLASP), a joint National Astronomical Observatory of Japan (NAOJ) and MSFC sounding rocket mission. The goal of the CLASP mission is to observe the scattering polarization in Lyman-α and to detect the Hanle effect in the line core. Due to the nature of Lyman-α polarization in the chromosphere, strict measurement sensitivity requirements are imposed on the CLASP polarimeter and spectrograph systems; science requirements for polarization measurements of Q/I and U/I are 0.1% in the line core. CLASP is a dual-beam spectro-polarimeter, which uses a continuously rotating waveplate as a polarization modulator, while the waveplate motor driver outputs trigger pulses to synchronize the exposures. The CCDs are operated in frame-transfer mode; the trigger pulse initiates the frame transfer, effectively ending the ongoing exposure and starting the next. The strict requirement of 0.1% polarization accuracy is met by using frame-transfer cameras to maximize the duty cycle in order to minimize photon noise. Coating the e2v CCD57-10 512x512 detectors with Lumogen-E coating allows for a relatively high (30%) quantum efficiency at the Lyman-α line. The CLASP cameras were designed to operate with ≤10 e$^-$/pixel/second dark current, ≤ 25 e$^-$ read noise, a gain of 2.0 and ≤0.1% residual non-linearity. We present the results of the performance characterization study performed on the CLASP prototype camera; dark current, read noise, camera gain and residual non-linearity.

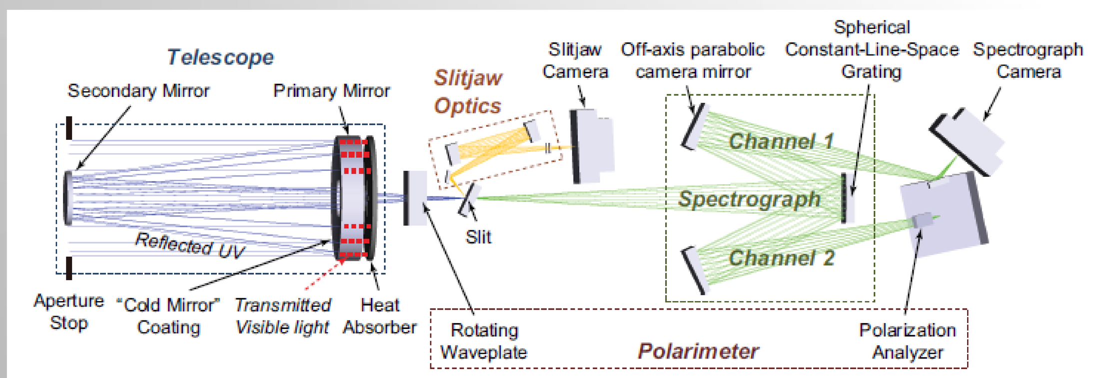
Introduction

The purpose of CLASP is to measure the linear polarization profiles caused by scattering processes and the Hanle effect in the Lyα line. The magnetic field information can be obtained from the measured Q/I and U/I profiles themselves and mainly through detailed radiative transfer modeling of the observed Lyα intensity and polarization using the most advanced magnetohydrodynamic models of the solar atmosphere. This will provide, for the first time, a diagnostic tool for magnetic field measurements in the upper chromosphere and transition region.



CLASP Instrument

- Cassegrain telescope, optimized for reflecting Lyα line (121.6 nm)
- Slit jaw imager for pointing verification
- The spectro-polarimeter produces two spectra simultaneously (corresponding to two orthogonal polarization states) on two separate CCD cameras.
- The rotation of the waveplate sends simultaneous trigger pulses to the spectrograph and polarization analyzer cameras to initiate frame transfer.



Telescope	
Type	Cassegrain
Aperture	ø277.4 mm
Eff. Focal Length	2614 mm (F/9.42)
Primary Mirror	ø290 mm (clear aperture), F/3.54
Secondary Mirror	ø119.4 mm
Visible Light Rejection	"Cold Mirror" coating on primary mirror

Slit	
Slit Width	18.4 µm (1.45 arcsec)
Slit Length	5.1 mm (400 arcsec)

Slitjaw Imaging System	
Wavelength	Lyα (band-pass filter)
Optics	- Fold mirror with multilayer coating - Off-axis parabola x 2 - Lyα filter x 2
Detector	512 x 512 CCD, 13µm pixel
Plate Scale	1.03 arcsec / pixel
Resolution	2.9 arcsec (spot RMS diameter)
FOV	527 arcsec x 527 arcsec

Polarimeter	
Measurements	Stokes I, Q, U
Capability	Simultaneous measurement of orthogonal polarizations
Optics	- Rotating 1/2 waveplate - Polarization analyzer x 2

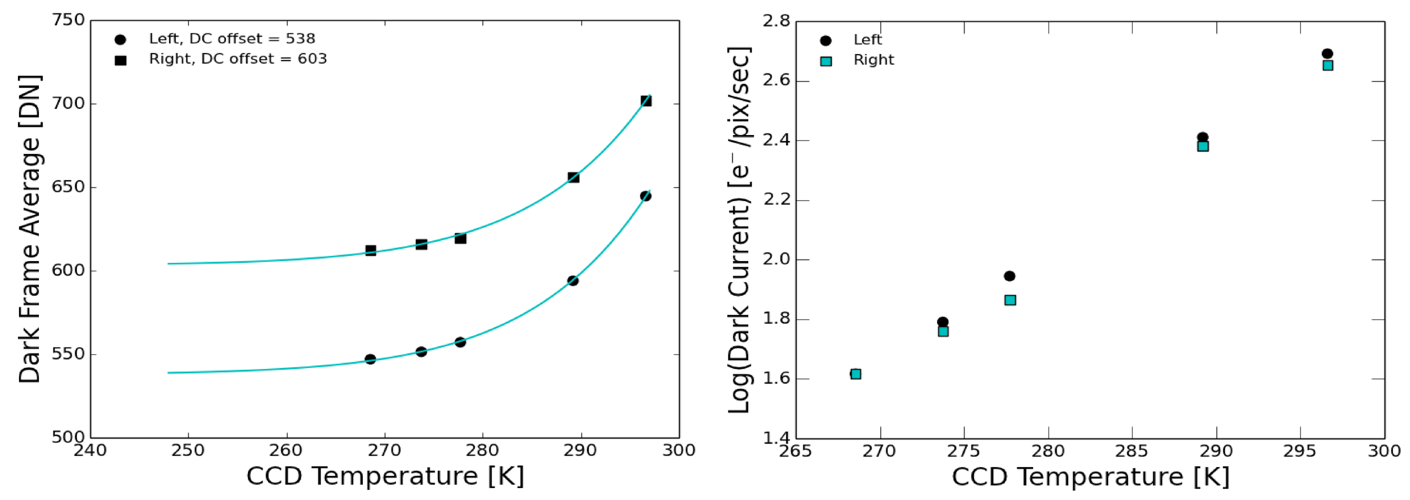
Spectrograph	
Spectrograph Type	Inverse Wadsworth mounting
Grating Type	Spherical constant-line-space with 3600 mm^{-1} groove density
Grating Size	ø106 mm (clear aperture)
Wavelength	Optimized for Lyα (121.567 nm)
Camera Mirror	Off-axis parabola
Resolution	0.01 nm (spectral; RMS diameter) 2.8 arcsec (spatial; RMS diameter)
Magnification	0.73

Spectrograph Cameras	
Detector	512 x 512 CCD, 13µm pixel
Exposure Time	0.3 sec (nominal)
Plate Scale	0.0048 nm / pixel (spectral) 1.40 arcsec / pixel (spatial)
Field of View	121.567±0.61 nm (spectral) 400 arcsec (along slit)

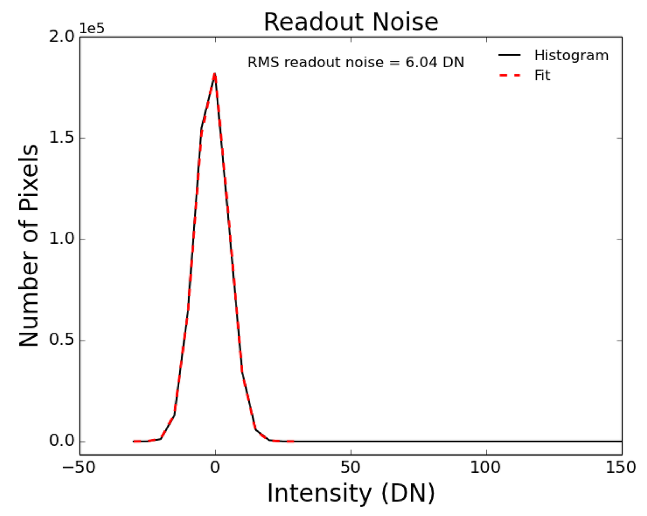
CLASP Science Camera Characterization

The CLASP mission requires the camera to operate with a stable gain (2.0 e$^-$/DN), low dark current (≤10 e$^-$/pix/sec), low read noise (≤ 25 e$^-$) and a residual non-linearity ≤ 0.1% to facilitate sensitive measurements of Lyα polarization modulation.

Dark Current & Read Noise



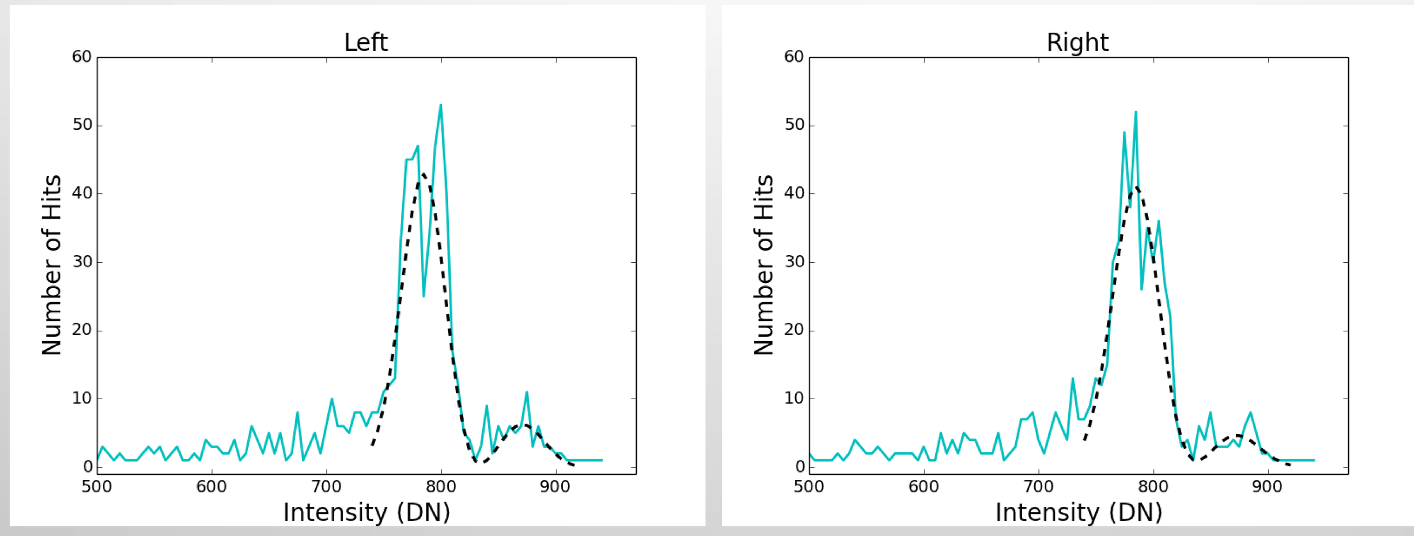
- Calculated a dark current at 268 K of 41 e$^-$/pix/sec for both left and right sides of the detector.
- Solving equation 1 for the flight set temperature of 253, and applying equation 2 yields a dark current of 7.1 e$^-$/pix/sec and 6.5 e$^-$/pix/sec for left and right sides, respectively.



- Read noise is measured by subtracting the master dark frame from a dark image, then calculating a histogram of the residual pixel values.
- The histogram is fitted with a Gaussian function, and the width of that Gaussian is the read noise of the camera.
- The CLASP requirement is a read noise ≤25 e$^-$.

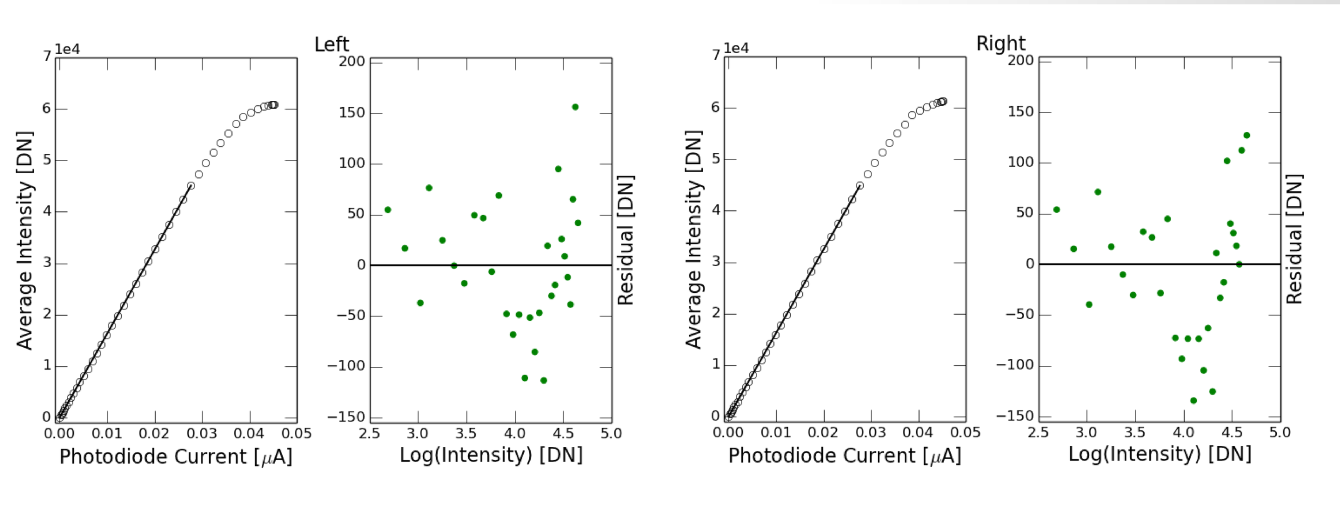
Camera Gain

- A 0.25 mCi ^{55}Fe X-ray source was used to measure the gain of the CCD and electronics chain.
- ^{55}Fe Mn $K_{\alpha,\beta}$ lines produce a number of electrons proportional to their energies when absorbed by silicon.
- The gain is determined by the location of the Mn $K_{\alpha,\beta}$ lines in the histogram of total ^{55}Fe X-rays detected.



Linearity

- Standard flat fielding techniques were used to determine the linearity of the CLASP camera.
- Variable output LED allowed the camera to expose from near dark levels, up to full saturation.
- A photodiode was placed next to the CCD to measure relative incident photon flux by reading the output current via picoameter.
- Residual non-linearity calculated by taking the ratio of the peak-to-valley deviation from the regression line, to the maximum intensity recorded in the dataset:



Conclusion

- Testing the CLASP prototype camera in a thermally controlled environment proved to be a sufficient method for characterizing and verifying the prototype's performance.
- The dark current at 268 K (-5 °C) was measured at e$^-$/pix/sec for both left and right sides of the CCD, while the dark current at the flight temperature of 253 K (-20 °C) was calculated at 7. 1 e$^-$/pix/sec for the left side and 6.8 e$^-$/pix/sec for the right side of the CCD.
- The average read noise was measured to be (XXX) (COMPARE TO REQUIREMENT).
- The gain was determined to be 2.03 and 2.05 for the left and right sides, respectively.
- Linearity of the prototype camera was determined to be 0.045% and 0.198% residual non-linearity for left and right sides, respectively.

Acknowledgements